The Design and Implementation of Open vSwitch

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Open vSwitch

What is Open vSwitch?

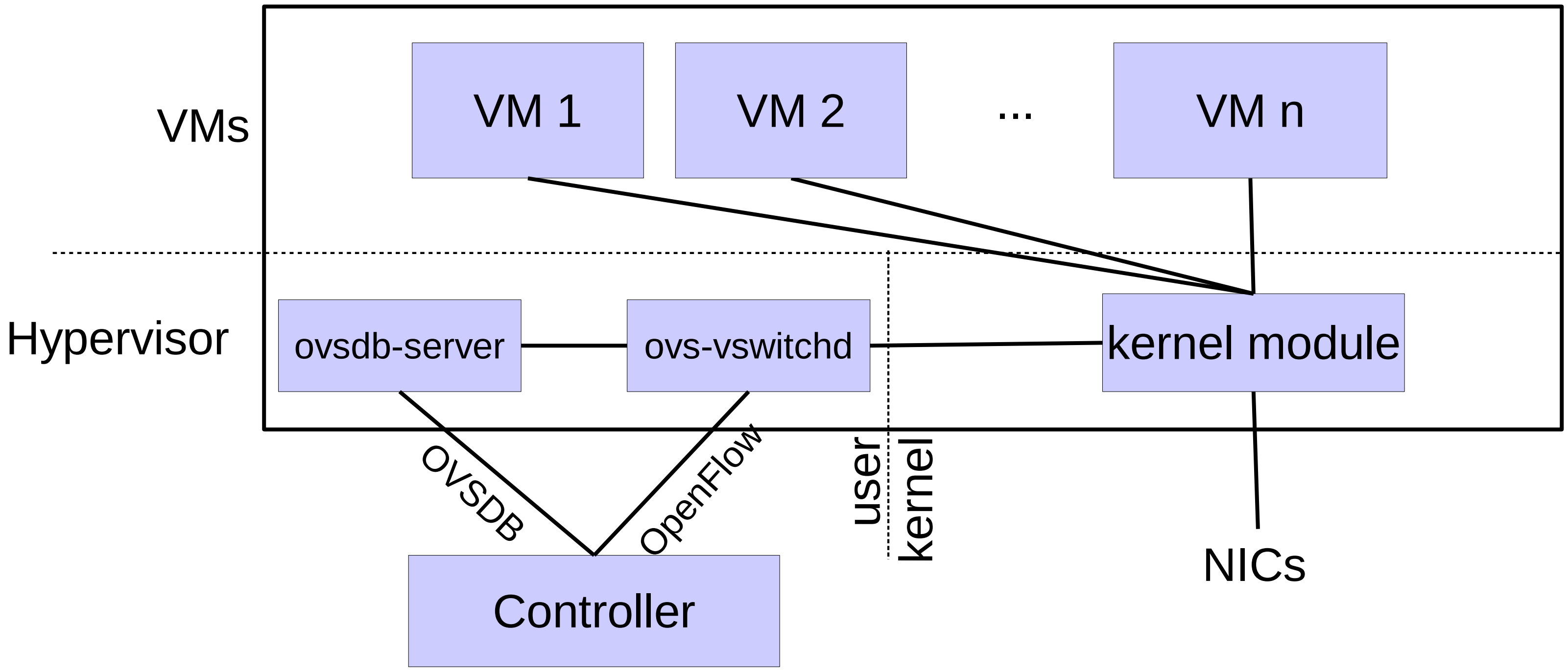
From openvswitch.org:

Open vSwitch is a production quality, multilayer virtual switch licensed under the open source Apache 2.0 license. It is designed to enable massive network automation through programmatic extension, while still supporting standard management interfaces and protocols (e.g. NetFlow, sFlow, SPAN, RSPAN, CLI, LACP, 802.1ag).

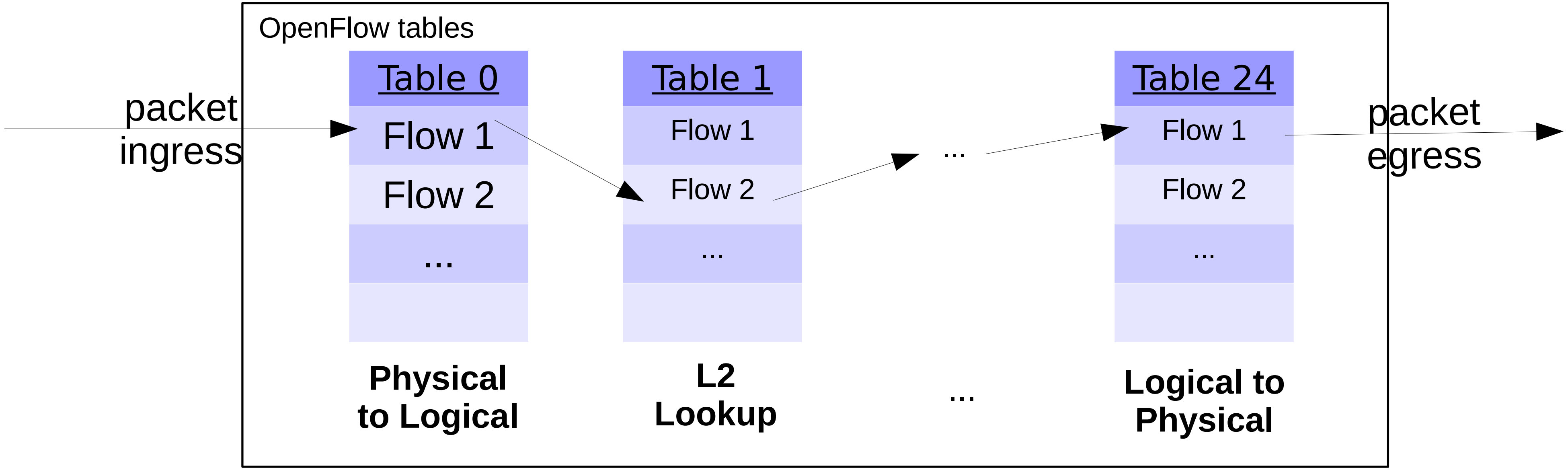
Where is Open vSwitch Used?

- Broad support:
  - Linux, FreeBSD, NetBSD, Windows, ESX
  - KVM, Xen, Docker, VirtualBox, Hyper-V, …
  - OpenStack, CloudStack, OpenNebula, …
- Widely used:
  - Most popular OpenStack networking backend
  - Default network stack in XenServer
  - 1,440 hits in Google Scholar

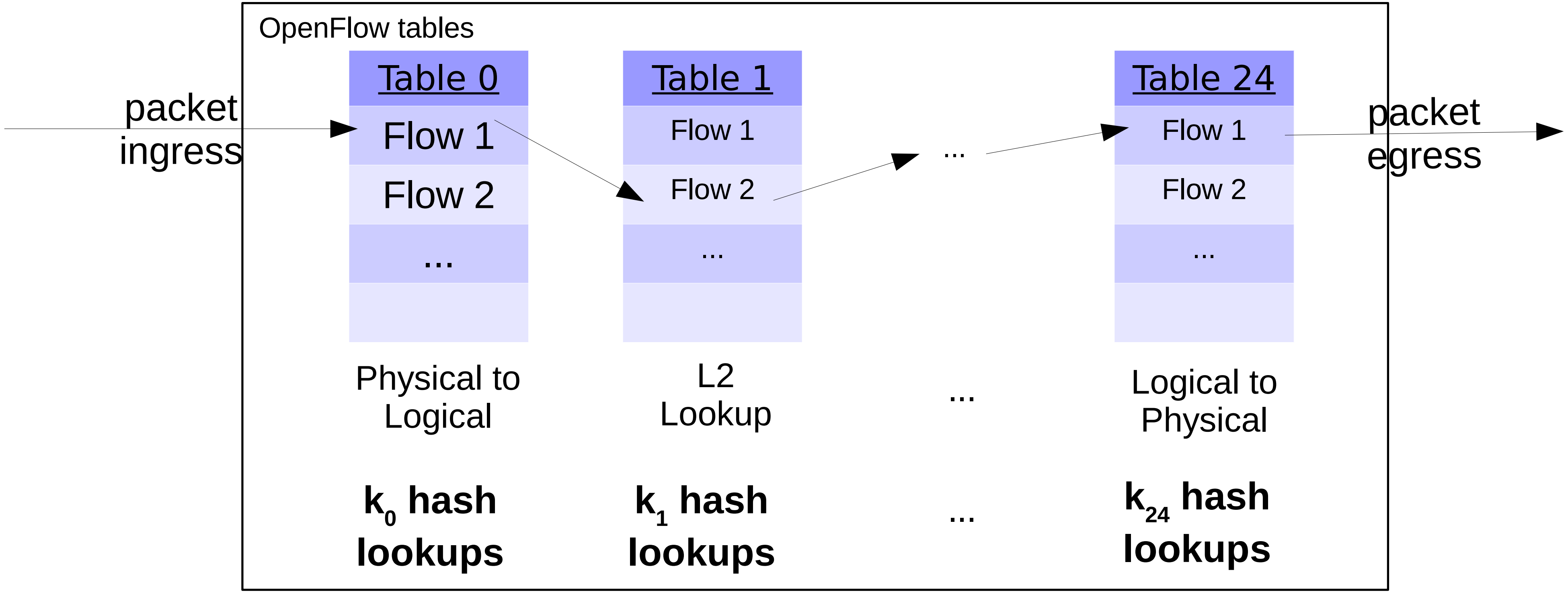
Open vSwitch Architecture



Network Virtualization Use Case



Implications for Forwarding Performance



100+ hash lookups per packet for tuple space search?

Non-solutions

- All of these helped:
  - Multithreading
  - Userspace RCU
  - Batching packet processing
  - Classifier optimizations
  - Microoptimizations
- None of it helped enough: % versus x.

Classification is expensive on general-purpose CPUs!

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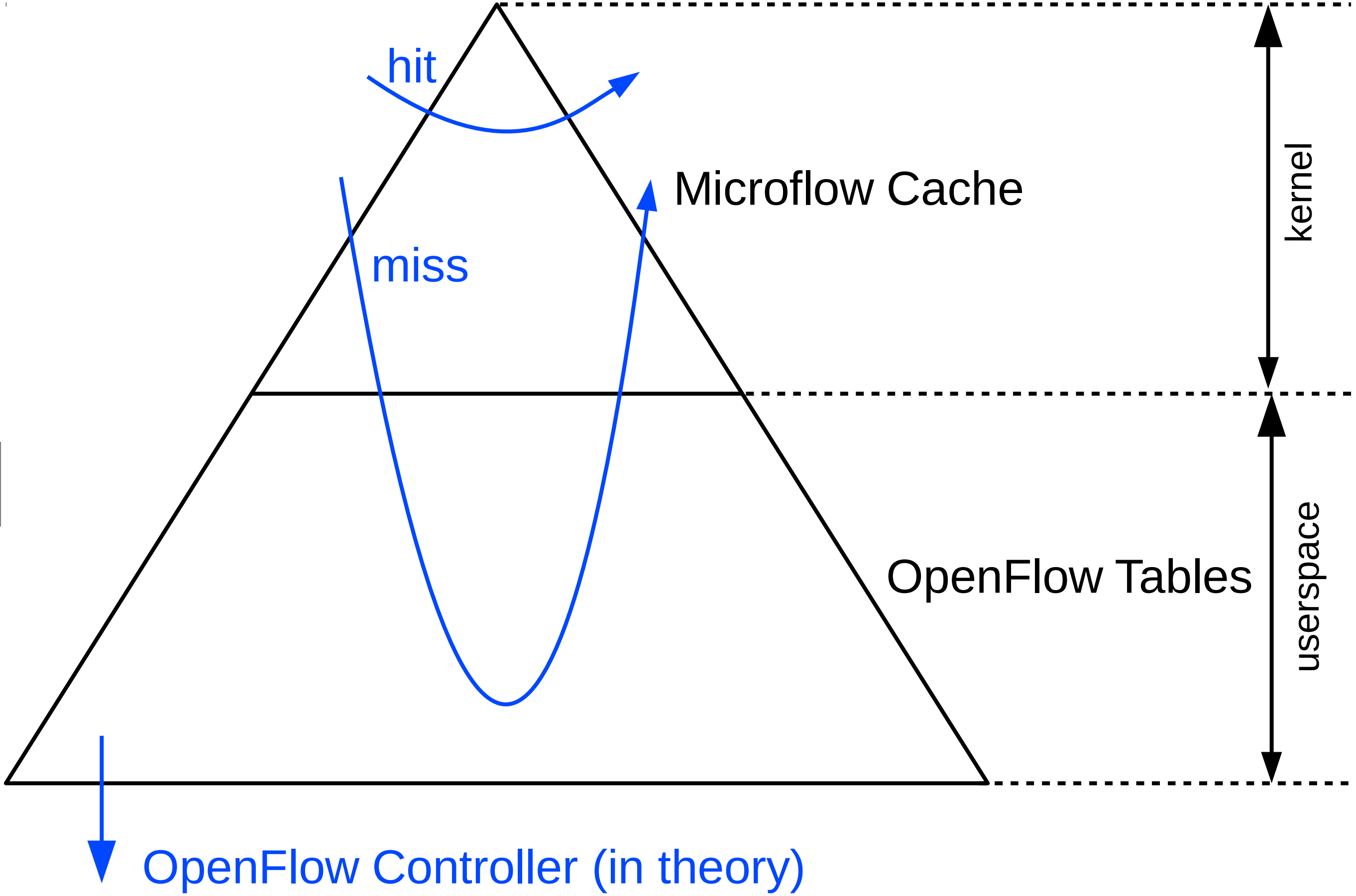
OVS Cache v1: Microflow Cache

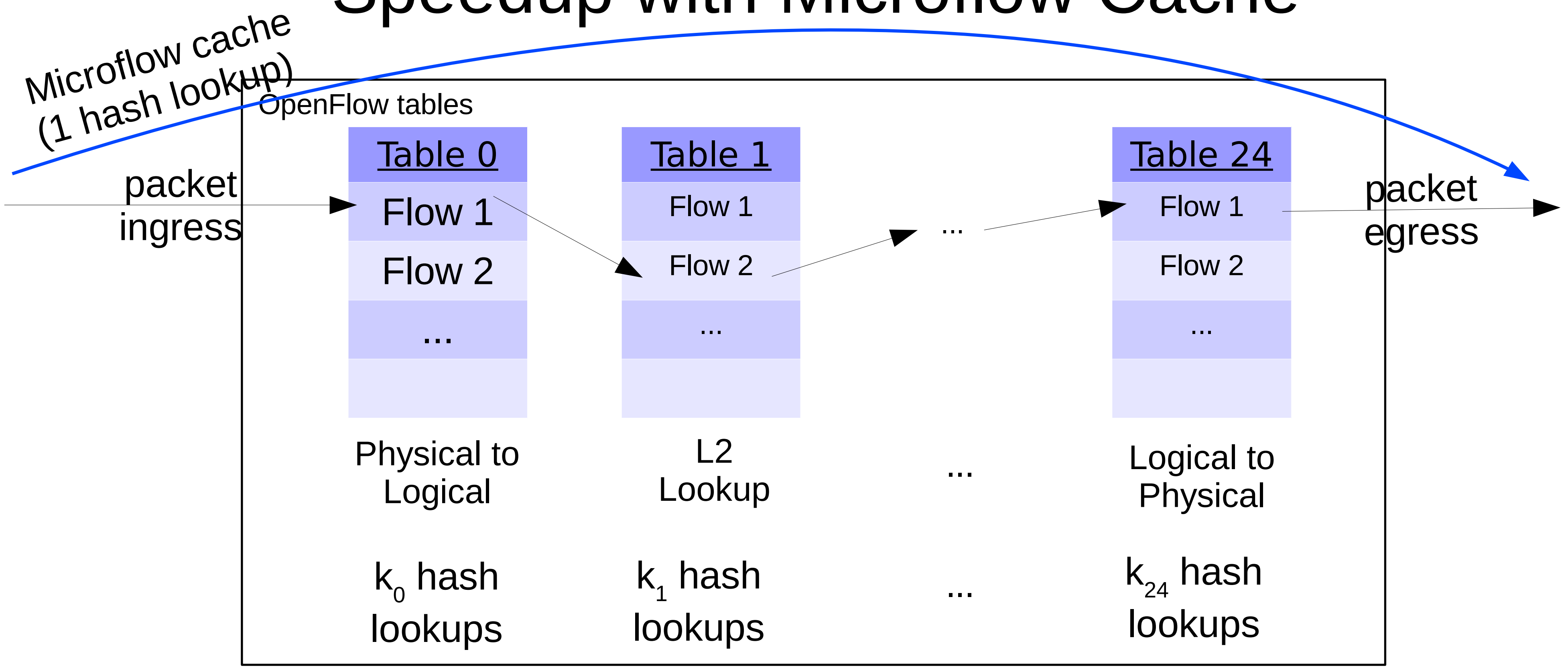
<u>Microflow:</u>

- Complete set of packet headers and metadata
- Suitable for hash table
- Shaded data below:

Eth	IP	TCP	payload



Speedup with Microflow Cache



From 100+ hash lookups per packet, to just 1!

Microflow Caching in Practice

- Tremendous speedup for most workloads
- Problematic traffic patterns:
  - Port scans
    - Malicious
    - Accidental (!)
  - Peer-to-peer rendezvous applications
  - Some kinds of network testing
- All of this traffic has lots of short-lived microflows
  - Fundamental caching problem: low hit rate

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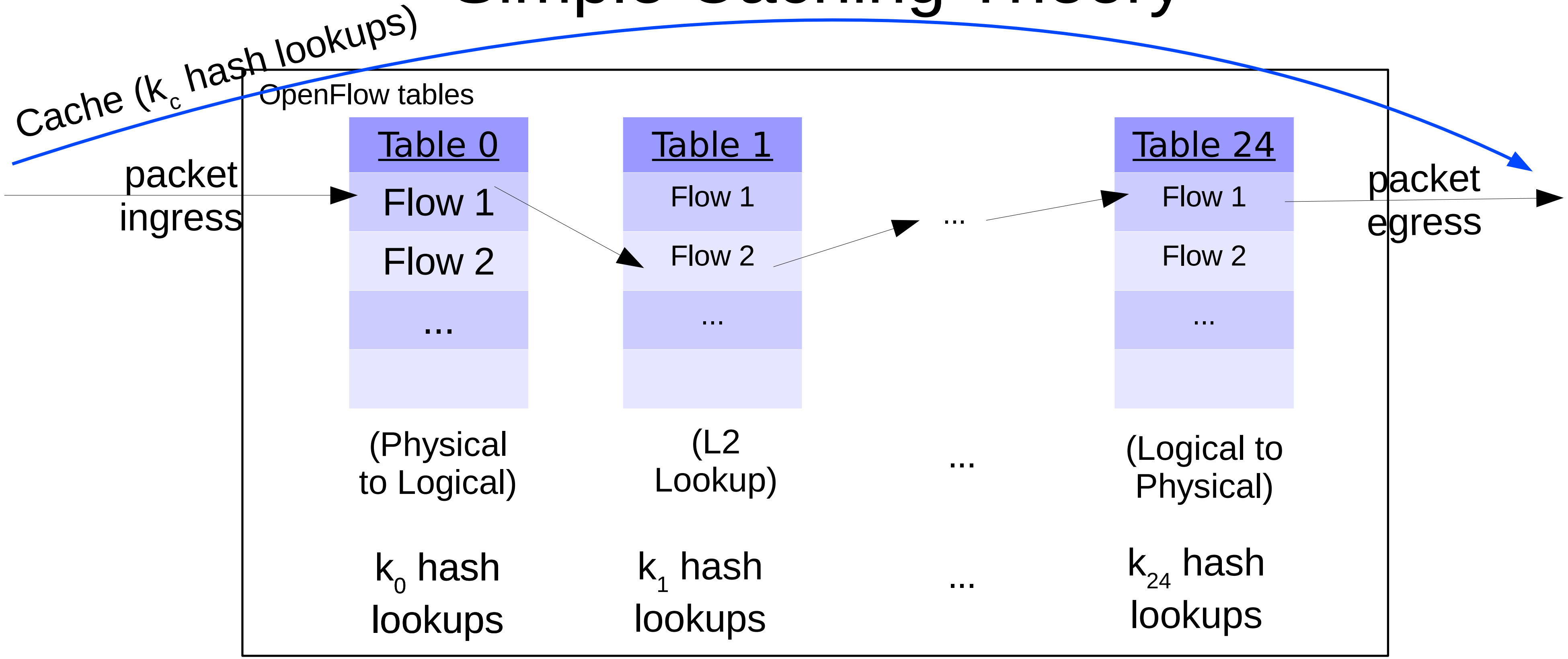
Simple Caching Theory



If $k_c << k_0 + k_1 + \ldots + k_{24}$: benefit!

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Naive Approach to Reducing Table Lookups

Combine tables 0...24 into one flow table. Easy! Usually, $k_c << k_0 + k_1 + \ldots + k_{24}$. But:

Table 0
ip_src=*a*
ip_src=*b*
ip_src=*c*
ip_src=*d*

n_1 flows

×

Table 1
ip_dst=*e*
ip_dst=*f*
ip_dst=*g*
ip_dst=*h*

n_2 flows

× ··· ×

Table 24
eth_dst=*i*
eth_dst=*j*
eth_dst=*k*
eth_dst=*m*

n_{24} flows

=

Table 0+1+...+24
ip_src=*a*, ip_dst=e, …, eth_dst=*i*
ip_src=*a*, ip_dst=e, …, eth_dst=*j*
ip_src=*a*, ip_dst=e, …, eth_dst=*k*
...
ip_src=*d*, ip_dst=*h*, …, eth_dst=*k*
ip_src=*d*, ip_dst=*h*, …, eth_dst=*m*

up to $n_1 \times n_2 \times \cdots \times n_{24}$ flows

“Crossproduct Problem”

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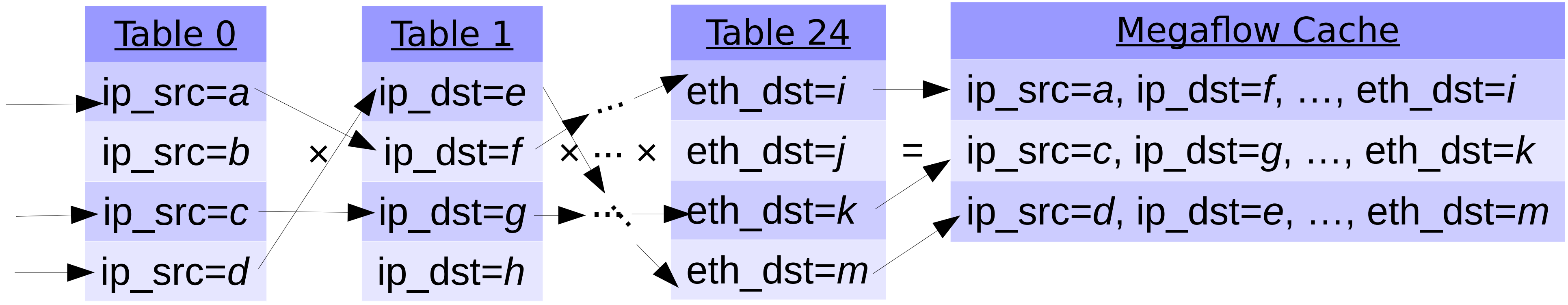
Lazy Approach to Reducing Table Lookups

Solution: Build cache of combined “megaflows” **lazily** as packets arrive.



n_1 flows

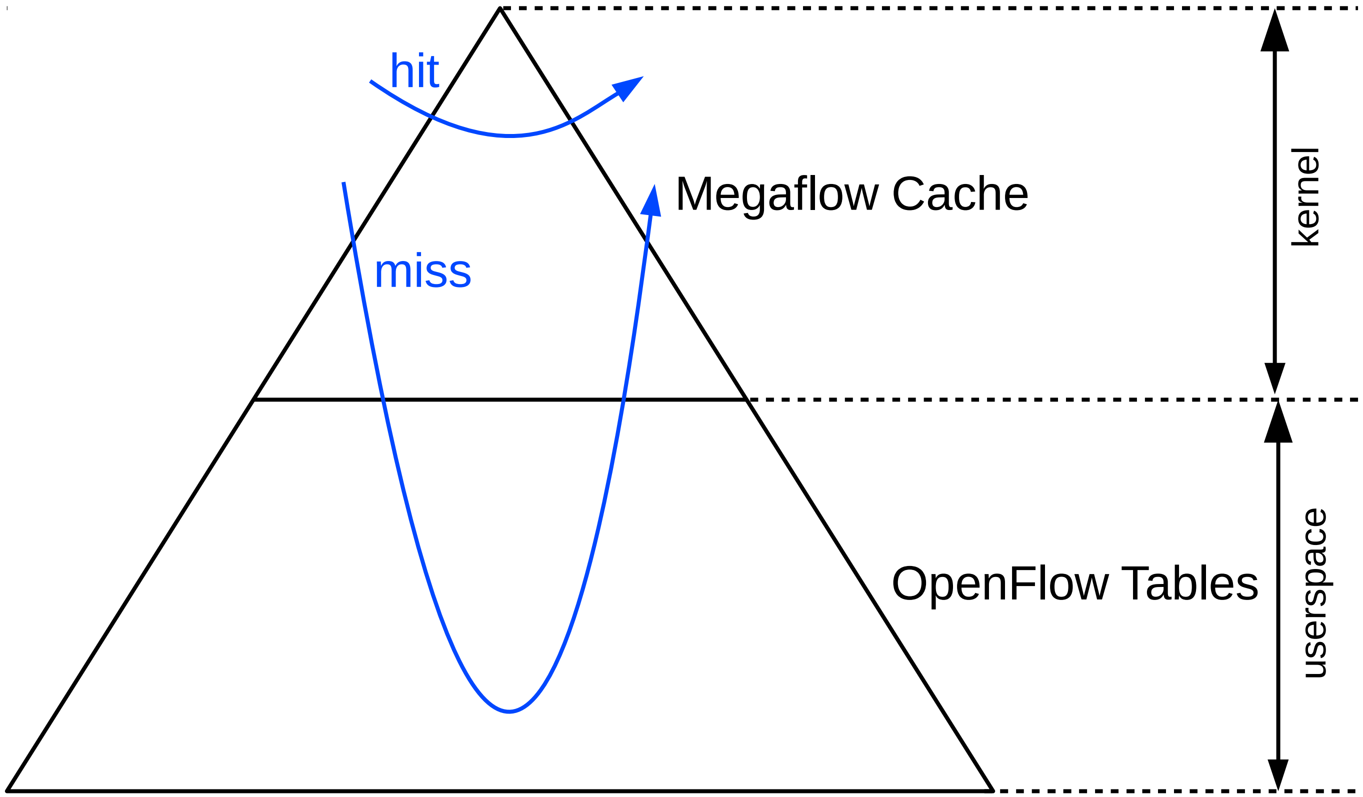
n_2 flows

n_{24} flows

populated **dynamically** only from actually observed packets

Same (or better!) table lookups as naive approach.
Traffic locality yields practical cache size.

OVS Cache v2: “Megaflow” Cache



Generating Good Megaflows

- Goal: Less-specific megaflows.
  - Megaflows that match TCP ports are almost like microflows!
  - Naive approach tends to match every field that appears anywhere in flow tables
- Requirements:
  - online
  - fast
- Contribution: Megaflow generation improvements (section 5).

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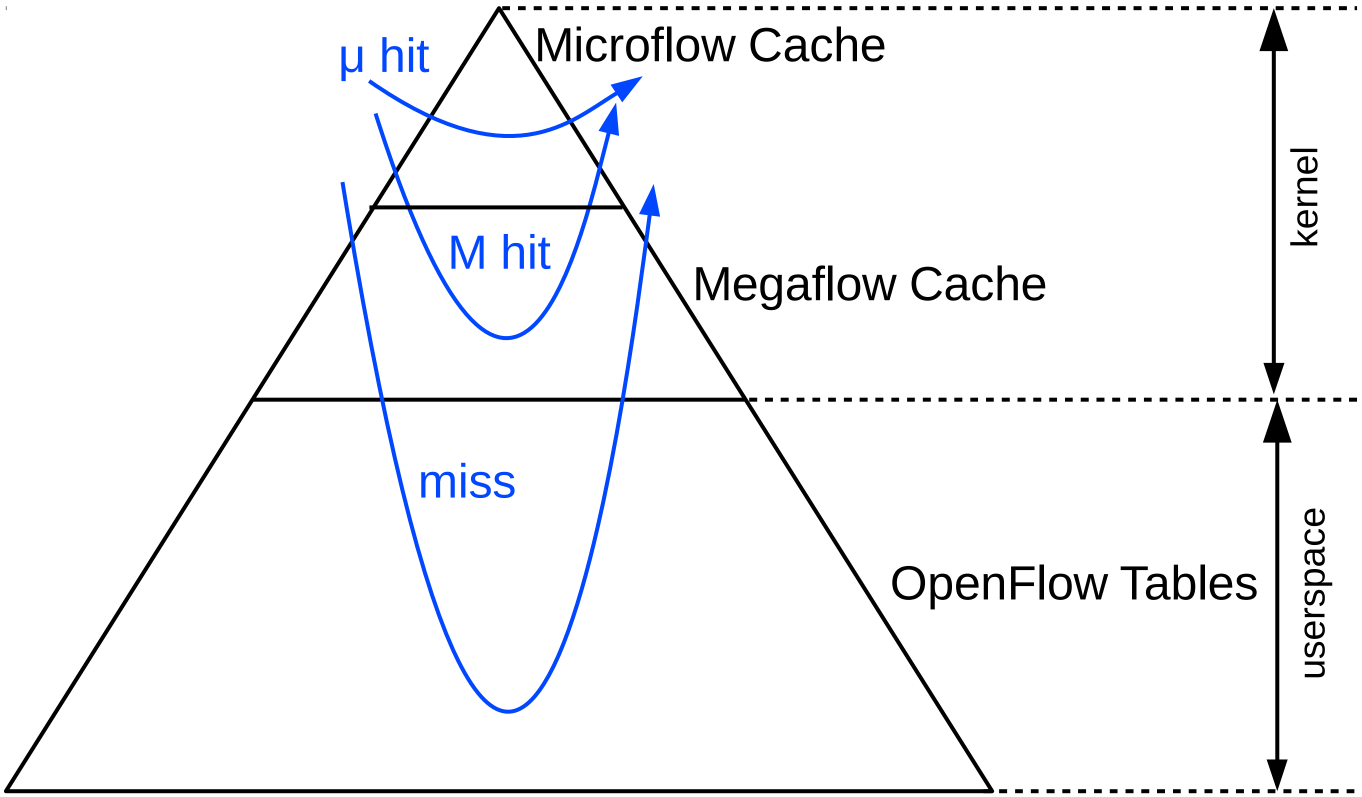
Megaflow vs. Microflow Cache Performance

- Microflow cache:
  - $k_0 + k_1 + \cdots + k_{24}$ lookups for first packet in microflow
  - 1 lookup for later packets in microflow
- Megaflow cache:
  - k_c lookups for every packet
- $k_c > 1$ is normal, so megaflows perform worse in common case!
- Best of both worlds would be:
  - k_c lookups for first packet in microflow
  - 1 lookup for later packets in microflow

OVS Cache v3: Dual Caches



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Parting Thoughts

- Common tension: expressibility vs. performance
- OpenFlow is expressive but amenable to high performance
- An application-specific switch would not be built like OVS
  - And would likely be **slower**
- Applications can freely evolve decoupled from performance
- Starting from a more general problem produced better results

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